Design Problem-Solving with External Representations

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Abstract: To develop a product out of a set of given variables and operators, complex information processing and the application of problem-solving strategies is needed. Unfortunately, these complex requirements on human problem-solving abilities are confronted with the designer's cognitive and creative limitations resulting from a restricted working-memory capacity. To overcome these limitations and to foster a creative and innovative product development, suitable supporting systems are needed. Their development should be based on a profound understanding of the cognitive actions and perceptual processes that are involved in design problem-solving. Thereby, a permanent exchange between internal thinking, reasoning and decision making steps and external writing, sketching and verbalisation steps takes place. The most challenging question in this context is how external representations should be configured and how interaction with these representations should be implemented to efficiently combine mental and motor actions. Another interesting question is, whether virtual environments are helpful for design problem-solving by providing information-rich, interactive visualisations in a 3D manner. To answer these questions and to deduce cognitively based guidelines for the development of design support systems, several experiments in virtual environments are planned in a laboratory setting.

1 Introduction

Considering the everyday practice of industrial product development, one has to ascertain that today's manufacturing companies are more and more confronted with increasing organisational and technical requirements: complex machines, facilities and automobiles have to be produced in a constantly increasing quality, in shorter time and for lower costs. The growing pressure to generate innovative products along with the demand for decreasing development periods additionally force organisations to carry out customer specific modifications on existing products and to develop different alternatives of one product type in real-time. Unfortunately, this rising demand on flexibility, efficacy and innovation is confronted with a complex and mostly inflexible development cycle. To compensate this disparity, organisations are obliged to search for suitable supporting systems which are able to speed up the time-consuming development process. Accordingly, research in this field deals with questions of how external supporting tools and functions should be configured and at which points of the development cycle they should be best applied to reduce production times and costs while satisfying highest quality affordances at the same time.

2 Theoretical Background

To organize and control design activities, knowledge structures and problem-solving operators which are stored in long-term memory have to be activated and executed in working memory to perform information processing [D95]. Remembering and processing both access the same cognitive resources, thereby causing a trade-off-relation between storage and execution in working-memory: on the one hand, high storage requirements only allow for a low processing quality, whereas on the other hand relevant information will be stored only provisory in working memory if it's processing affords great demands on memory capacities [BH74]. Accordingly, working memory represents the bottleneck of creative thinking and results in a considerable decrease in solution quality if overloaded [HSW96]. This overload in turn causes an unintended loss of design information. Correspondingly, designers adapt their processing to the limited cognitive resources and work with simplified, inappropriate and subjective representations or approximate problem-solving strategies [K95]. During solution finding they confine themselves to work with already common strategies and are not able to process complex procedures in parallel. To foster creative ideation processes anyway, a relief of working-memory during design problem-solving is essential. This intent can only be managed by externalising internal problem representations and solution approaches, thereby saving mental capacities for complex problem-solving. Considering the described deficiencies and limitations of human thought together with the resulting necessity for a mental support of the designer, externalized forms of internal problem states constitute an important tool to simplify problem-solving. People often use external representations to clarify the problem statement, to identify spatial relations and to release working memory capacity. Additionally, external representations support idea generation and reflection processes and help evaluating design concepts. By integrating external representations in design processes and actively interacting with them, designers are able to offload internal, cognitive processes on external, perceptive-motor actions, thereby setting working memory capacities free for efficient and creative problem solutions.

3 Research Questions

Current theories view problem-solving with external representations within a theoretical framework of distributed cognition [H95]. Following that theoretical approach, cognitive actions occur both internally and externally, whereas external representations are not only peripheral supports to cognition, but coincide with internal representations, thereby stretching a distributed representation space for problem-solving. Inherent properties of external representations structure the problem and even change the nature of a task, because they constrain the range in which subtasks are carried out internally and how people interact with external representations. In consequence, performance in distributed tasks involves a trade-off between the use of internal cognitive resources and external perceptual-motor processes [Ke08]. In this context, minimal memory theory claims that people offload cognitive processes on perceptual-motor processes whenever it is possible thereby reducing mental workload [Ba97].

In contrast, soft constraint theory assumes that perceptual-motor processes are not necessarily preferred over cognitive processes, but that internal and external processes are integrated most efficiently [Gr06]. In this theoretical view, cognitive, perceptual and motor resources are allocated flexibly depending on their relative utility and their resulting cognitive costs. That in turn means that the allocation of cognitive resources over internal and external representations reliably informs about the potential usefulness of external representations for solving certain problem types.

The aim of this research project is to investigate, whether designers could benefit from immersive, information rich 3D visualizations during idea generation, conceptual design and design review. Another research goal is to answer the question, how designers can be optimally supported in interacting with external representations in 3D environments. As a psychological foundation, the theory of distributed cognition will be applied to design problem-solving in virtual environments [H95]. Following this theoretical approach, cognitive actions occur both internally and externally thereby stretching a distributed representation space for problem-solving. As the research area of distributed cognition is still very young, not much is known about the way, how internal and external representations are used for inference or deduction processes and about what is processed internally and what externally. Additionally, the question how external representations facilitate problem-solving is discussed contradictorily. To prove this assumption, minimal memory theory will be tested against soft constraint hypothesis in a comparative experiment in the domain of design problem-solving. It is planned to systematically vary several parameters of external representations in virtual environments (1-to-1 perspective, dimensionality, complexity, information richness). The hypothesis is that different combinations of parameters are specifically useful for different design tasks (e.g. idea generation, analysis, and conceptualization). The overall goal of this research is to deduct cognitively based guidelines for the embodiment of external representations in virtual environments to optimally foster design problem-solving.

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